NASA/CR—2004-213306

Parametric Analyses of Potential Effects on Stratospheric and Tropospheric Ozone Chemistry by a Fleet of Supersonic Business Jets Projected in a 2020 Atmosphere

M. Dutta, K. Patten, and D. Wuebbles
University of Illinois, Urbana Campus, Urbana, Illinois

October 2004

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at 301–621–0134
- Telephone the NASA Access Help Desk at 301–621–0390
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

NASA/CR—2004-213306

Parametric Analyses of Potential Effects on Stratospheric and Tropospheric Ozone Chemistry by a Fleet of Supersonic Business Jets Projected in a 2020 Atmosphere

M. Dutta, K. Patten, and D. Wuebbles
University of Illinois, Urbana Campus, Urbana, Illinois

Prepared under Contract C–70341–T

National Aeronautics and
Space Administration

Glenn Research Center

October 2004

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

Available electronically at http://gltrs.grc.nasa.gov

Parametric Analyses of Potential Effects on Stratospheric and Tropospheric Ozone Chemistry by a Fleet of Supersonic Business Jets Projected in a 2020 Atmosphere

M. Dutta, K. Patten, and D. Wuebbles
University of Illinois, Urbana Campus
Urbana, Illinois 61801

Introduction

A class of new supersonic aircraft for business purposes is currently under consideration for use starting around 2015 to 2020. These aircraft, which can accommodate about 12 to 13 passengers, will fly at a speed of Mach 1.6 to 2 and are commonly termed as Supersonic Business Jets (SSBJs). A critical issue that needs to be addressed during the conception phase of such aircraft is the potential impact of emissions from such aircraft on the atmosphere especially on stratospheric ozone.

Although these SSBJs will be much smaller in size and will have smaller engines than the hypothetical fleets of commercial passenger High Speed Civil Transport (HSCT) aircraft that we have studied previously (Dutta et al., 2002), they will still emit nitrogen oxides ($NO_x = NO + NO_2$), carbon dioxide (CO_2), water vapor (H_2O) and sulfur, the latter if it is still in the fuel. Thus, it is important to design these SSBJs in a manner so that a projected fleet of these aircraft will not have a significant effect on ozone or on climate.

This report analyzes the potential impact of a fleet of SSBJs in a set of parametric analyses that examine the envelope of potential effects on ozone over a range of total fuel burns, emission indices of nitrogen oxides [E.I.(NO_x)], and cruise altitudes, using the current version of the UIUC zonally-averaged two-dimensional model of the global atmosphere.

Methodology

Description of Scenarios

A set of emissions scenarios for the future SSBJs has been developed for the Ultra-Efficient Engine Technology (UEET) Program at the NASA Glenn Research Center by Baughcum et al (2002). The variables chosen for the parametric studies to evaluate the effects of atmospheric effects of SSBJs were fuel burn, cruise altitude and emission index of NOx. Fuel sulfur content was not considered in this parametric study because the effects are small and it is generally thought that sulfur will be eliminated from the fuel over the next few decades.

Fuel burn is a function of the fleet size, utilization rate and aircraft engine technology. A supersonic business jet would have a much smaller fuel use at cruise since such aircraft are expected to be much smaller than other high speed civil transport or other commercial airliner. The total fuel burn for the projected fleet of SSBJs was treated parametrically and values of 6, 12, 18, and 24 Mlbs/day values were used.

Choice of the emission index for NO_x is an important issue since much of the concern regarding the atmospheric effects of aircraft emissions arise from NO_x amounts. For this study, emission indices of 10 and 20 g/kg fuel were considered for all the fuel burn cases. This range includes both current and projected engine technology.

Three two kilometer altitude bands ranging from 13 to 19 kilometers (representation of these in our model is in log pressure altitude) were chosen for evaluating the effect of cruise altitudes on ozone concentrations so that emissions were put into the bands of 13-15, 15-17 and 17-19 km.

Since the two-dimensional model uses a grid based on pressure coordinates with 1.5 km between zones, the emissions were spread across two model layers of the model. The pressure grid of the emissions was remapped onto our pressure grid. Also, after zonally averaging, the emission file was remapped from its one-degree latitude distribution onto the 5-degree latitude resolution of the model.

In the model, the background atmosphere was based on IPCC (2001) projections for a 2020 atmosphere with the source gas concentrations of the long-lived species set according to Table 1. This choice of background concentrations of long-lived constituents is based on the A2 scenario recommended in IPCC (Houghton et al., 2001). Scenario A2 is in the upper middle of the range of scenarios being used for analyzing the potential effects of human activities on climate. The scenarios were analyzed relative to the corresponding 2020 base with a subsonic aircraft included based on 2020 projected subsonic aircraft traffic and corresponding emissions developed by Baughcum et al. (2002). The SSBJ scenarios were then evaluated for their effects on ozone relative to this background atmosphere.

Table 1.—Background surface concentrations in 2020 for long-lived gases, based on scenario A2 in IPCC (2001).

	2020
CFC-11 (pptv)	214
CFC-12 (pptv)	486
CFC-13 (pptv)	72
CC14 (pptv)	59
HCFC-22 (pptv)	229
CH3CC13 (pptv)	1
HCFC-141b (pptv)	16
Halon-1301 (pptv)	3.0
Halon-1211 (pptv)	3.0
CH3Cl (pptv)	550
CH3Br (pptv)	7.34
CH_4 (ppbv)	1997
N_2O (ppbv)	335
CO_2 (ppmv)	**417**

Model Description

The UIUC two-dimensional chemical radiative-transport model of the chemistry and physics of the global atmosphere is a zonally-averaged model to study human related and natural forcings on the global atmosphere. The model determines the atmospheric distributions of 78 chemically active atmospheric trace constituents. The model domain extends from pole to pole and from the ground to 84 km. A grid in the model represents 5 degrees of latitude and 1.5 km in log-pressure altitude. In addition to 56 photolytic reactions, the model incorporates 161 thermal reactions in the chemical mechanism, including heterogeneous reactions. (Wei et al., 2001)

The current 2002 version of the UIUC 2D model has some key improvements incorporated in it. Major upgrades to the solution technique of residual mean meridional circulation (RMMC) and the treatments of atmospheric dynamics were made through better representation of the effects of planetary waves and a more accurate method for determining the RMMC. Both planetary waves of wave numbers 1 and 2 are considered with real boundary topography and boundary winds. Latent heating and the sensible heat flux were specified based on GCM results, which are more physically meaningful. An accurate and fast longwave radiation code for the height of surface to 60 km is adopted in the radiation part of the model. The improvements in the treatment of the infrared radiation and RMMC solution technique are discussed in Choi and Youn (2001). The zonally averaged temperature and wind fields are specified based on 6-year climatology of the United Kingdom meteorological Office (UKMO) reanalysis data. In addition, background diffusion coefficients, which cannot be explicitly obtained in the model, are also tuned for the "leaky pipe" model and the model barrier between tropics, mid-latitudes, and Polar Regions. All the upgraded components of this version of the model are briefly described in Table 2 (Dutta et al., 2002)

In the current version of the model the chemistry has been updated according to JPL 00-3 recommendations (DeMore et al., 2000). This particularly affects the nitrogen oxide chemistry, the N_2O_5 and $ClONO_2$ hydrolysis and several HOCl and HCl reactions. HOBr and HOCl cross-sections and the O3 photolysis quantum yields are updated as well.

All of these changes in the model have resulted in the improved representation of the distributions of age of air, which means better model transport in the "age of air" concept (Hall and Plumb, 1994; Hall et al., 1999). The upgraded components make the model mean age distribution closer to the observed features described in the NASA-sponsored "Models and Measurements II" (Park et al, 1999). The mean age distribution of the current UIUC 2D model shows the tropical pipe structure in the tropics as expected. Much older mean age at higher latitudes and higher altitudes are also derived, in much better comparison with observations.

Results and discussion

A total of 24 SSBJ scenarios have been evaluated for this study. All the results are obtained from steady state model simulations where the model is run for 10 years with the same species input, heating rates input and climatological input files and differing aircraft emission input files according to the scenarios studied. Table 1 gives the total column ozone change, global and for the two hemispheres separately, for four cases of fuel burns and two emission indices of nitrogen oxides. For the highest cruise altitude band of 17-19 km, the total column ozone changes, for all cases of fuel burn and emission indices of NO_x are shown in Table 2.

In Table 1, for the cruise altitude band 13-15 km, there is no net total ozone depletion for the cruise altitude band 13-15 km. This can be attributed to the fact that in the upper troposphere and lowest altitudes of the stratosphere, ozone can be formed instead of destroyed by higher nitrogen oxide concentrations due to chemistry similar to the chemistry creating urban ozone. Thus, for any given latitude, there is a crossover point above which NO_x destroys ozone and below which NO_x produces ozone. For the higher E.I.(NO_x) case of 20 g/kg of fuel, there is relatively more net formation of ozone in the lower cruise altitude band.

From the two tables it is also observable that the impact in the Northern Hemisphere total column ozone change is more than double that of the impact in the Southern Hemisphere. Due to enhancement in the treatment of dynamical processes in this version of the model, there is an increased transport of NO_x across the equatorial region. Nonetheless, the SSBJ air traffic in the Northern Hemisphere is projected to be such that the Northern Hemisphere impact outweighs that of the Southern Hemisphere.

The maximum change in local ozone depletion amongst all the scenarios is 0.16 %, which is found for the higher total fuel burn of 24 Mlbs/day and E.I.(NO_x) = 20 g/kg and the highest cruise altitude band of 17-19 km. For the most probable scenario of 18 Mlbs/day , E.I.(NO_x) of 20 g/kg of fuel and flying at 15-17 km , the maximum local ozone depletion is calculated to be 0.038 %.

The trend of the percentage change in the Northern Hemisphere total column ozone for changing fuel burn for emission indices of 10 and 20 g/kg of fuel are studied in Figures 1 and 2 respectively. We can see that the relation is linear for the lower two altitude bands but not quite so for the highest cruise altitude band. This slight nonlinearity is still under evaluation. For the first cruise altitude band of 13-15 km, there is a slight increase in ozone for reasons stated earlier.

Figure 3 presents the calculated column ozone impact for the Northern Hemisphere as a function of cruise altitude for the two E.I.(NO_x) and the two fuel burn cases of 12 and 18 Mlbs/day. In this figure the altitude sensitivity of the studies show the point in the lower atmosphere where the effect on ozone transitions from a positive effect on ozone to a negative impact. The inflexion point is near 14.5 km.

Figure 4 shows the relationship between percentage change in total column ozone for all latitudes with respect to seasons for the fuel burn of 18 Mlbs/day, E.I.(NO_x) of 20 g/kg of fuel and cruise altitude of 15-17 km case. Figure 5 depicts the percentage change in ozone profile for the same case and it is plotted for June 2020. From Figure 4, we see that there is an ozone minimum of around 0.037 % depletion around the North Pole region during the month of October.

Figure 5 corroborates the fact that there is an intense ozone loss region around the northern higher latitudes and around the altitude range of the aircraft emission injection. This is expected due to the fact that most of projected air traffic would be in the Northern Hemisphere. Although the SSBJ aircraft emissions are primarily in the Northern Hemisphere mid-latitude region, the maximum ozone loss is observed at Northern Hemisphere high latitudes. This is because of the effects of atmospheric transport processes.

In Figure 6 we see the percentage change in water vapor in the upper tropospheric/lower stratospheric region for the same case of 18Mlbs/day fuel burn, E.I.(NOx) 20 g/kg of fuel and flying at cruise altitude band of 15-17 km. There is a net positive change of more than 0.48 % for water vapor between 15-18 km altitude in the northern hemisphere.

Similarly Figure 7 shows the percentage change in NO_x for the same case and the maximum change is observed in the same region of northern hemisphere mid-latitude between 15-18 km altitude. This is obvious because of the maximum flight paths being between 30-60 degrees latitude in the Northern Hemisphere.

Table 2.—Percentage change in ozone for SSBJ scenarios relative to 2020 background atmosphere for altitude bands 13-15 and 15-17 km. NH and SH correspond to the total ozone change in the Northern and Southern Hemispheres, respectively. Global corresponds to the globally-averaged change in total ozone. Max and Min correspond to the maximum and minimum change in local ozone throughout the stratosphere.

Fuel burn, Mlbs/day	**E.I.(NOx),** g/kg of fuel	**Altitude band,** (km)	**NH**	**Percentage ozone impact (%), SH**	**Global**	**Min**	**Max**
6	10	**13-15**	0.00077	0.00038	0.00057	0.0001	0.0019
	20		0.00150	0.00068	0.00109	0.00019	0.0038
12	10		0.00147	0.00067	0.00107	0.00019	0.0036
	20		0.00292	0.00129	0.00211	0.00037	0.0074
18	10		0.00203	0.00070	0.00137	-0.00071	0.0051
	20		0.00413	0.00152	0.00282	-0.00048	0.0104
24	10		0.00294	0.00113	0.00204	-0.00091	0.0073
	20		0.00591	0.00244	0.00417	-0.00039	0.0150
6	10	**15-17**	-0.00201	-0.00134	-0.00168	-0.0063	-0.00219
	20		-0.00380	-0.00200	-0.00289	0.00118	-0.0036
12	10		-0.00406	-0.00221	-0.00313	-0.00126	0.0221
	20		-0.00779	-0.00409	-0.00594	-0.0241	0.0072
18	10		-0.0064	-0.00365	-0.00502	-0.0196	0.0176
	20		-0.0121	-0.00654	-0.00934	-0.00371	0.00803
24	10		-0.00829	-0.00440	-0.00634	-0.025	0.0046
	20		-0.0162	-0.00826	-0.0122	-0.04969	0.0141

Table 3.—Same as Table 2 but for 17 to 19 km

Fuel burn, Mlbs/day	**E.I.(NOx),** g/kg of fuel	**Altitude band,** (km)	**NH**	**Percentage ozone impact (%), SH**	**Global**	**Min**	**Max**
6	10	**17-19**	-0.0088	-0.0061	-0.0076	-0.0321	-0.003
	20		-0.0159	-0.00951	-0.01270	-0.0429	-0.0434
12	10		-0.0178	-0.0118	-0.0148	-0.0559	-0.0061
	20		-0.0323	-0.0188	-0.0255	-0.0871	-0.00899
18	10		-0.0268	-0.0174	-0.022	-0.0746	-0.0093
	20		-0.0458	-0.0274	-0.0366	-0.120	-0.013
24	10		-0.0302	-0.0213	-0.0259	-0.0734	-0.011
	20		-0.0608	-0.0355	-0.0482	-0.161	-0.014

Figure 1.—Percentage change in Northern Hemisphere total column ozone as a function of total fuel burn for different cruise altitude bands for E.I.(NO_x) = 10 g/kg of fuel.

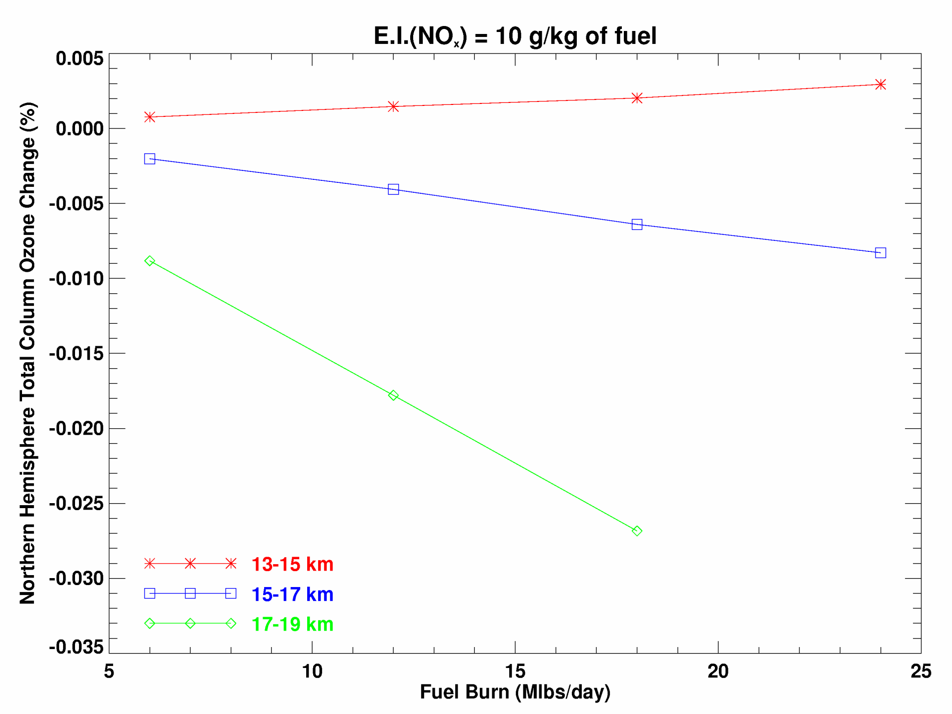


Figure 2.—Percentage change in Northern Hemisphere total column ozone as a function of total fuel burn for different cruise altitude bands for E.I.(NO_x) = 20 g/kg of fuel.

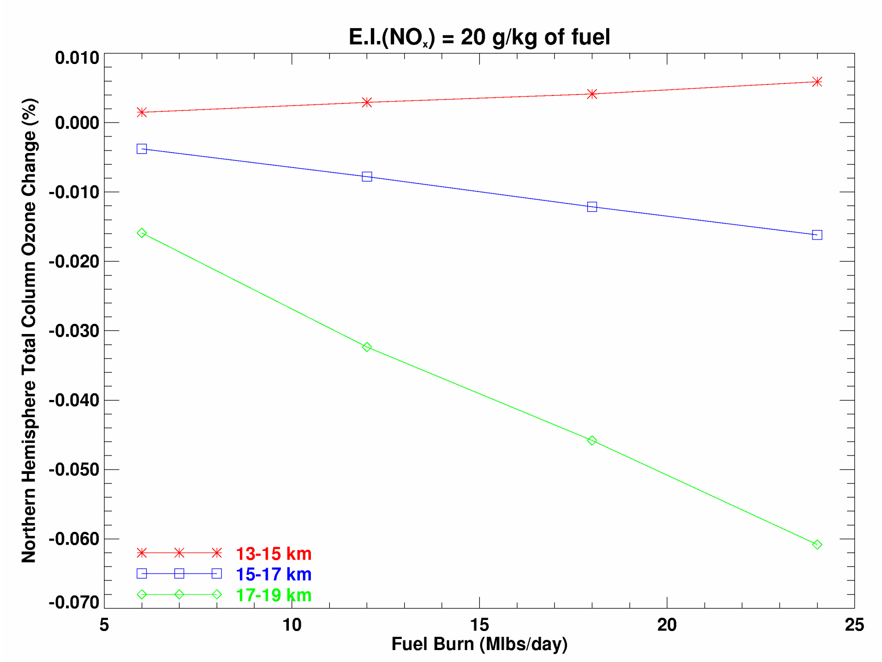


Figure 3.—Calculated total column ozone impact for the Northern hemisphere as a function of cruise altitude for E.I.(NOx) = 10 and 20 g/kg of fuel for two fuel burns of 12 and 18 Mlbs/day respectively.

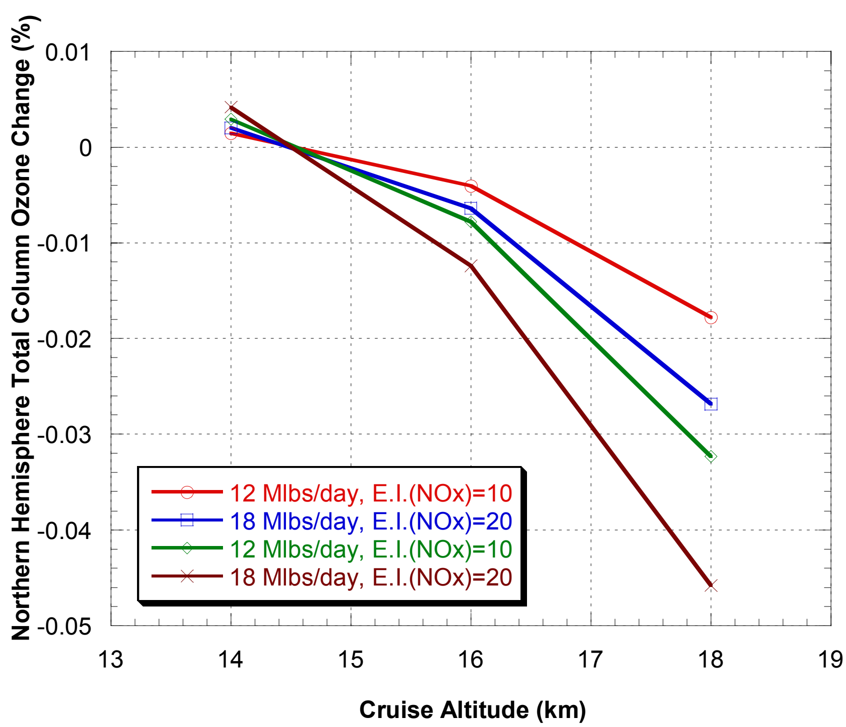


Figure 4.—Percentage change in total column ozone for SSBJ having fuel burn of 18 Mlbs/day , E.I.(NO_x) = 20 g/kg of fuel and flying at a cruise altitude centered around 16 km.

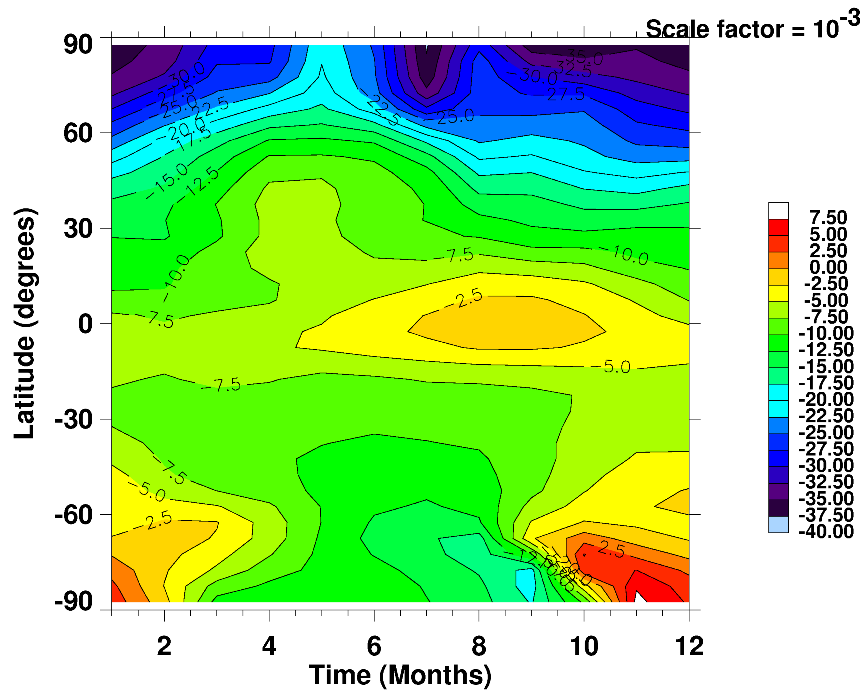


Figure 5.—Percentage change in ozone profile for SSBJ having fuel burn of 18 Mlbs/day , E.I.(NO_x) = 20 g/kg of fuel and flying at a cruise altitude centered around 16 km in June, 2020.

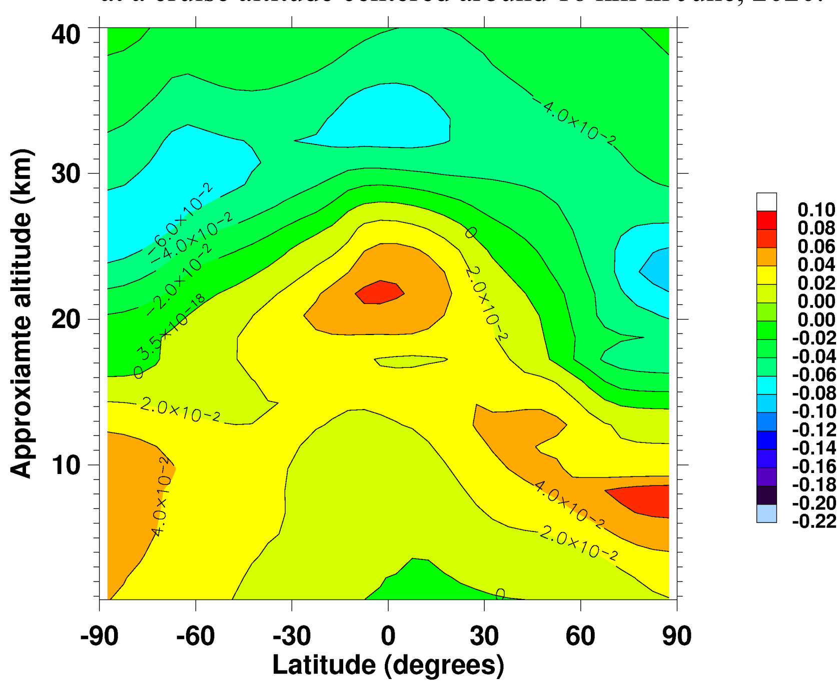


Figure 6.—Percentage change in water vapor for SSBJs having fuel burn of 18 Mlbs/day , E.I.(NO_x) = 20 g/kg of fuel and flying at a cruise altitude centered around 16 km in June 2020.

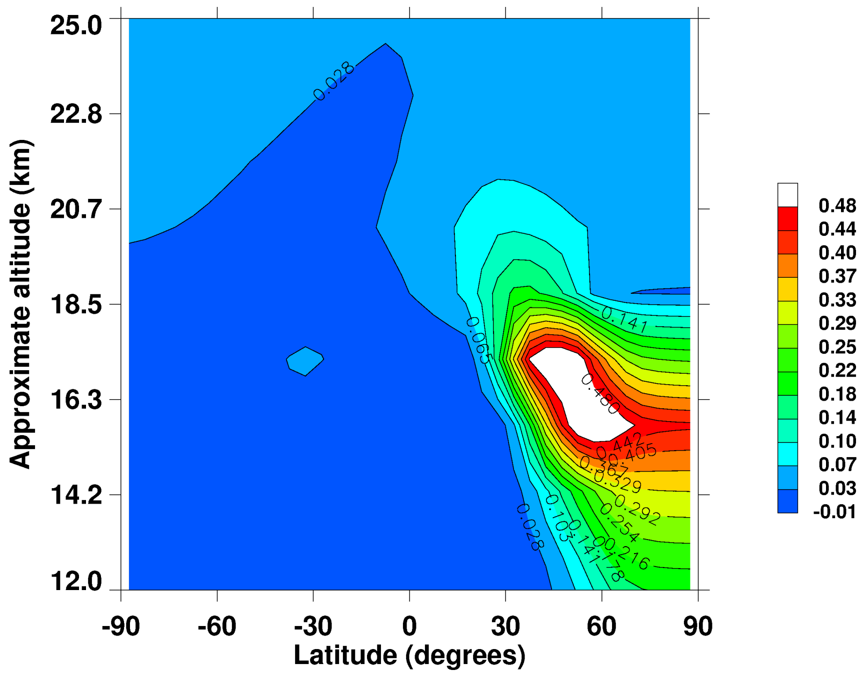
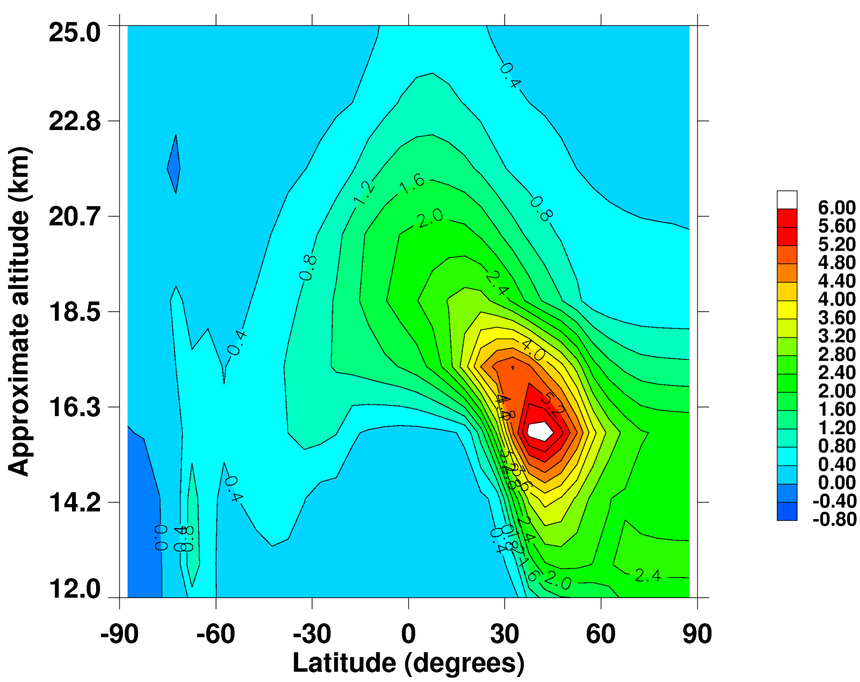


Figure 7.—Absolute change in NOx (in ppb) due to a fleet of QSJs having total fuel of 18 Mlbs/day, E.I.(NO_x) = 20 g/kg of fuel and flying at an approximate altitude centered around 16 km in June 2020.



Conclusions

- In this study of the potential impact of a fleet of SSBJs, the maximum local ozone depletion, even for the highest E.I.(NO_x) of 20 g/kg of fuel, fuel burn of 24 Mlbs/day and highest cruise altitude case, was found to be below 0.17%. Total ozone changes in the Northern Hemisphere are 0.061% or less.

- For the most probable scenario of 18 Mlbs/day , E.I.(NO_x) of 20 g/kg of fuel and flying at 15-17 km , the maximum local ozone depletion is calculated to be 0.038%.

- The relationship between the fuel burn and ozone depletion is almost linear.

- The altitude in the atmosphere above which ozone depletion begins due to these projected flights happens to be around 14.5 km.

- Very little effect is observed in the Southern Hemisphere due to the fleet of SSBJs.

- This study provides crucial information for determining the optimum fuel burn, emission index of NOx and cruise altitude of the projected fleet of Supersonic Business jets, such that ozone depletion in the lower stratosphere is kept to minimum.

References

Arakawa, A. and W.H. Schubert, 1974: Interactions of cumulus cloud ensemble with the large-scale environment. Part I. *J. Atmos. Sci.*, **31**, 671-701.

Bacmeister, J.T., D.E. Siskind, M.E. Summers, and S.D. Eckermann, 1998: Age of air in a zonally averaged two-dimensional model, *J. Geophy. Res.*, **101**, 1457-1461.

Baughcum, S., 2002: First Order Ozone Impact of a Fleet of Supersonic Business Jets (SSBJS). Report prepared for NASA Glenn Research Center, The Boeing Company, Seattle, NASA/CR—2002-211898, p 35.

Choi, W. 1995: On the meridional circulation in the transformed Eulerian mean system, *J. Korean. Meteor. Soc.*, **31**, 325-337.

Choi, W., 1996: Eddy mixing by the planetary wave in the stratosphere. *J. Korean. Meteor. Soc.*, **32**, 41-50.

Choi, W. and D. Youn, 2001: Effects of physical and numerical schemes on model-calculated ozone distribution in the stratosphere, *K. J. Atmos. Sci.*, **3**, 39-52.

DeMore, W.B., et al., *Chemical Kinetics and Photochemical Data for Use in Stratospheric Modeling*., Evaluation Number 12, NASA/JPL Publication 97-4, Pasadena, CA., 1997.

Dutta, M., D. Youn, K. Patten, and D. Wuebbles, A Comparison of HSCT emissions scenario results from the UIUC-2D model with the IPCC (1999) assessment, Report prepared for NASA Glenn Research Center and The Boeing Company, Seattle, 2002, p 22.

Fleming, E.L., C.H. Jackman, R.S. Stolarski, and D.B. Considine, Simulation of stratospheric tracers using an improved empirically based two-dimensional model transport formulation, *J. Geophys. Res*., **104**, 23911-23934, 1999.

Garcia, R.R. and S. Solomon, 1994: A new numerical model of the middle atmosphere, 2, Ozone and related species. *J. Geophys. Res.*, **99**, 12,937-12,951.

Garcia, R.R., F. Stordal, S. Solomon, and J.T. Kiehl, 1992: A new numerical model of the middle atmosphere, 1. Dynamics and transport of tropospheric source gases. *J. Geophys. Res.*, **97**, 12,967-12,991.

Gettelman, A., J.R. Holton, K.H. Rosenlof, 1997: Mass fluxes of O_3, CH_4, N_2O and CF_2CL_2 in the lower stratosphere calculated from observational data, *J. Geophys. Res*., 102, 19149-19159.

Hall, T.M., D.W. Waugh, K.A. Boering , and R.A. Plumb, 1999: Evaluation of transport in stratospheric models, *J. Geophys. Res*., **104**, 18,815-18,839.

Hall, T.M. and R.A. Plumb, 1994: Age as a diagnostic of stratospheric transport. *J. Geophys. Res.*, **99**, 1059-1069.

Houghton, J.T., et al., 2001:*Climate Change 2001 the Scientific Basis*. Appendix II, IPCC, pp 807-816.

IPCC, 1999: Aviation and the Global Atmosphere. J. E. Penner, et al., editors, Cambridge University Press.

Isaksen, I., et al., Modeling the Chemical Composition of the Future Atmosphere**,** in *Aviation and the Global Atmosphere: A special Report of IPCC*, Penner, Lister et al, chap 4, pp121-163,Cambridge University Press, Cambridge, UK, ,1999.

Jones, D.B.A., A.E. Andrews, H.R. Schneider, and M.B. McElroy, 2001: Constraints on meridional transport in the stratosphere imposed by the mean age of air in the lower stratosphere, *J. Geophy. Res.*, **106**, 10,243-10,256.

Kawa, S.R., et al., 1999: *Assessment of the Effects of High-Speed Aircraft in the Stratosphere: 1998,* NASA/TM-209237, chap 4, Greenbelt, Maryland, pp 71-101.

Kim, J.K., 1999: Parameterization of land surface processes in an atmospheric general circulation model. Ph. D. Thesis, Seoul National University, p 178.

Kinnison D.E., P.S. Connell., J.M. Rodriguez, D.A. Rotman, D.B. Considine, J. Tannahill, R. Ramaroson, P.J. Rasch, A.R. Douglass, S.L. Baughcum., L. Coy, D.W. Waugh, S.R. Kawa, and M.J. Prather,. 2001: The Modeling Initiative assessment model: Application to high-speed civil transport perturbation, *Journal of Geophysical Research* **106**,1693-1711.

Kotamarthi, V.R., D.J Wuebbles, and R.A. Reck, 1999: Effects of nonmethane hydrocarbons on lower stratosphere and upper tropospheric chemical climatology in a two-dimensional zonal average model, *Journal of Geophysical Research* **102**,3671-3682.

Li, L., T.R. Nathan, and D.J. Wuebbles, 1995: Topographically forced planetary wave breaking in the stratosphere, *Geophys. Res. Lett*., **22**, 2953-2956.

Li, S. and D.W. Waugh, 1999: Sensitivity of mean age and long-lived tracers to transport parameters in a two-dimensional model, *J. Geophy. Res.*, **104**, 30,559-30,569.

Manney, G.L., R. Swinbank, S.T. Massie, M.E. Gelman, A.J. Miller, R. Nagatani, A. O'Neill, and R.W. Zurek, 1996: Comparison of U.K. Meteorological Office and U.S. National Meteorological Center stratospheric analysis during northern and southern winter, *J. Geophy. Res.*, **101**, 10,311-10,334.

Matsuno, T., 1995: *Climate system dynamics and modeling.* Center for Climate System Research, University of Tokyo, 341 pp.

Nathan, T.R., E.C. Cordero, L. Li, and D.J. Wuebbles, 2000: Effects of planetary wave-breaking on the seasonal variation of total column ozone, *Geophy. Res. Lett.*, **27**, 1907-1910.

Olaguer, E.P., H. Yang, and K.K. Tung, 1992: A reexamination of the radiative balance of the stratosphere, *J. Atmos. Sci.*, **49**, 1242-1263.

Park, J.H., M.K.W. Ko, C.H. Jackman, R.A. Plumb, and K.H. Sage (eds.), 1999: *Models and Measurements II*. NASA Langley Research Center, Hampton, VA, p 496.

Randel, W. and R. Garcia, 1994: Application of a planetary wave breaking parameterization to stratospheric circulation statistics, *J. Atmos. Sci.*, **51**, 1157-1168.

Sander, S.P., et al., 2000: *Chemical Kinetics and Photochemical Data for Use in Stratospheric Modeling*., *Supplement to Evaluation number 12: Update to Key Reactions,* Evaluation Number 13, NASA/JPL Publication 00-3, Pasadena, CA, p 73 .

Schneider, H.R., D.B.A. Jones, and M.B. McElroy, 2000: Analysis of residual mean transport in the stratosphere 1. Model descript and comparison with satellite data, *J. Geophys. Res*., **105**, 19991-20011.

Schoeberl, M.R., A.E. Roche, J.M. Russell III, D. Ortland, P.B. Hays, and J.W. Waters, 1997: An estimation of the dynamical isolation of the tropical lower stratosphere using UARS wind and trace gas observations of the quasi-biennial oscillation, *Geophy. Res. Lett.*, **24**, 53-56.

Shia, R.-L., M.K.W. Ko, D.K. Weisenstein, C. Scott, and J. Rodriguez, 1998: Transport between the tropical and midlatitude lower stratosphere: Implications for ozone response to high-speed civil transport emissions, *J. Geophys. Res*. **103**, 25435-25446.

Swinbank, R. and O'Neill, 1994: A.,Quasi-biennial and semi-annual oscillations in equatorial wind fields constructed by data assimilation**,** *Geophys. Res. Lett.,* **21**, 2099-2102.

Wei, C.-F., S.M. Larson, K.O. Patten, and D.J. Wuebbles, 2001:Modeling of ozone reactions on aircraft-related soot in the upper troposphere and lower stratosphere, *Atmospheric Environment,* **35**, 6167-6180.

Wuebbles, D.J., K. Patten, M.T. Johnson, and R. Kotamarthi, New Methodology for Ozone Depletion Potentials of short-lived compounds:n-Propyl bromide as an example, *J. Geophys. Res*., **106,** 14,551-14,571, 2001.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 2004	Final Contractor Report

4. TITLE AND SUBTITLE

Parametric Analyses of Potential Effects on Stratospheric and Tropospheric Ozone Chemistry by a Fleet of Supersonic Business Jets Projected in a 2020 Atmosphere

5. FUNDING NUMBERS

WBS–22–714–09–03
C–70341–T

6. AUTHOR(S)

M. Dutta, K. Patten, and D. Wuebbles

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Illinois
Department of Atmospheric Sciences
Urbana Campus
Urbana, Illinois 61801

8. PERFORMING ORGANIZATION REPORT NUMBER

E–14753

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR—2004-213306

11. SUPPLEMENTARY NOTES

Project Manager, Chowen C. Wey, Vehicle Technology Directorate, NASA Glenn Research Center, organization code 0300, 216–433–8357.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Categories: 01 and 45 Distribution: Nonstandard

Available electronically at http://gltrs.grc.nasa.gov

This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

A class of new supersonic aircraft for business purposes is currently under consideration for use starting around 2015 to 2020. These aircraft, which can accommodate about 12 to 13 passengers, will fly at a speed of Mach 1.6 to 2 and are commonly termed as Supersonic Business Jets (SSBJs). A critical issue that needs to be addressed during the conception phase of such aircraft is the potential impact of emissions from such aircraft on the atmosphere especially on stratospheric ozone. Although these SSBJs will be much smaller in size and will have smaller engines than the hypothetical fleets of commercial passenger High Speed Civil Transport (HSCT) aircraft that we have studied previously, they will still emit nitrogen oxides ($NO_x = NO + NO_2$), carbon dioxide (CO_2), water vapor (H_2O) and sulfur, the latter if it is still in the fuel. Thus, it is important to design these SSBJs in a manner so that a projected fleet of these aircraft will not have a significant effect on ozone or on climate. This report analyzes the potential impact of a fleet of SSBJs in a set of parametric analyses that examine the envelope of potential effects on ozone over a range of total fuel burns, emission indices of nitrogen oxides [E.I.(NO_x)], and cruise altitudes, using the current version of the UIUC zonally-averaged two-dimensional model of the global atmosphere.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Supersonic business jet; Ozone depletion; Atmospheric impact	20
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	